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SALINE WATER CONVERSION

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The future of saline water conversion in providing high quality water will be limited to the area of water treatment and is not likely to be used as a salinity control procedure for maintaining instream water quality. It will be used to provide water that is sold directly to users that can afford high cost water. Three process categories are described: vapor, liquid, and solid phase separation. Economic considerations are reviewed along with pilot plant applications and commercial uses. A bibliography is included.

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SALINE WATER CONVERSION

INTRODUCTION

The process of saline water conversion in itself is not a salinity control procedure. It can be used, however, and probably will be used to a larger extent in the future as a source of fresh water, particularly in the western States. This is true in specific inland areas where brackish water is a problem and on the coasts where for all practical purposes, the sea provides an infinite quantity of water supply. To date, the process has only been used to provide water for municipal and industrial use, and the process is too expensive to consider for "instream" salinity control. None of the desalinization processes have been, or will be, developed to the point where it can provide water at current irrigation water prices ($1.00 to $3.00 per acre foot).

The conversion of saline water to fresh water is not new, but the current quest is for a process to convert large volumes at low costs. Moorehead (1) noted that in 1867 two condensers were used in Zula, Ethiopia to produce 160 tons of fresh water per day (40,000 gpd) to support the British Army during the invasion of Ethiopia. About the same time, another application was made in Chile (2) in 1870 where a 50,000 square foot solar still was built to supply water to a mining camp. The capacity was probably about 1,000 gpd. These were undoubtedly relatively expensive processes.

Several studies have been made during the last ten years on reducing unit cost of production in a basic research program on development of low cost conversion. The Saline Water Act of 1952 as amended in 1955 and 1961 has provided considerable money for basic research and also applied research. However, before discussing the research projects on results, or the

commercial application, each of the conversion processes will be described briefly. Since some of the processes are good for brackish or saline water, these terms will have the meaning prescribed by Wolman (3) and Faust (4) who agree on the TDS characterizations as follows:

Slightly brackish	1,000 - 3,000 ppm
Moderately brackish	3,000 - 10,000 ppm
Highly brackish	10,000 - 33,000 ppm
Sea water	33,000 - 36,000 ppm
Brine	36,000 - + ppm

Summary of Processes

The processes can be divided into three general categories, vapor, liquid, and solid phase separation processes. The vapor processes include distillation and evaporation. The liquid processes include membranes (osmosis and electrodialysis), solid extraction, and controlled diffusion. Solid phase processes include freezing, hydrates, ion exchange, and absorption.

The distillation process is being used primarily for desalting sea water (5). The commercially feasible process are vapor, compression distillation, multiple-effect distillation, and flash evaporation. The first process is an application of the heat pump where the vapor is compressed with accompanying increase in temperature and then returned to the evaporator where the water condenses and liberates heat used to evaporate more water. The input energy is mechanical rather than thermal, (i.e., for compressor power). Multiple effect distillation employs the use of a series of boiling chambers or "effects". The vapor from the first effect moves to the second effect where it liberates heat and causes evaporation of brine and this is repeated through any number of effects. There is a point of diminishing return as

each successive effect evaporates less water than the previous one. Flash evaporation utilizes the principal that under reduced pressure water will boil at a correspondingly lower temperature. The near-boiling brine losses heat as it passes through each chamber, but the pressures in succeeding chambers are reduced to compensate for the loss in water temperature. The big disadvantages in distillation processes are scaling and corrosion. Nevertheless, the processing appears to be the most economical for conversion of waters of high salinity.

Solar distillation is very simple in principal. The advantages are that is requires no outside energy, equipment and physical facilities are simple, it requires no moving parts, no pre-treatment is required, and the finished water is of good quality. Scaling is not a problem. The disadvantages are diurnal fluctuation in operation, limitation to location, potential wind and hail damage, and large land area requirements (2). (A rule of thumb is 5,000 acre-feet per day) However, units as large as 100,000 gpd appear reasonable.

The membrane processes are the most promising for conversion of brackish waters (6). Two principal processes are electrodialysis, in which energy is supplied by an electric current, and reverse osmosis, in which energy is supplied as pressure (for sea water about 350 psi to overcome osmotic pressure). Electrodialysis is the only process currently in use for demineralizing brackish waters. The process uses DC electricity to cause migrations of salts and minerals through special ion permeable membranes. Alternate membranes allow only cations or anions to pass, and thus the water in every other compartment is demineralized. It is the most econonical

process to date for demineralization of brackish waters.

The process which holds promise for the future is that of freezing (7). It has the disadvantage of being a solid phase process, and with this the difficult problem of separating frozen crystals from the brine. The advantages are that it is a low energy process, accomplished at atmospheric pressure, and at a low temperature which minimized problems of scaling and corrosion. Two processes have possibilities for sea water conversion; freezing evaporation and direct refrigerant cooling. In the first, the latent heat of fusion is removed by evaporating a portion of pre-cooled sea water at reduced pressure. The second process involves vaporizing a refrigerant in direct contact with the sea water. It is believed that when certain design features and construction material costs are optimized, fresh water will be economically produced by this method.

Several other processes are under investigation but do not appear to have the potential of those processes mentioned above. One of these is the solvent extraction process (6) in which an organic solvent is used to extract water from a brine solution. The solvent is then separated from the water by changing temperature. Another method is the hydrate process (6) whereby low-molecular-weight hydrocarbons, or their halogen derivatives, are used to combine with water and form solid clathrate substances. Clathrates reject ionic substances and accept only pure water as the hydrate crystals are formed. This is similar to ice crystal formation except that it is a molecule in which one substance is included in the crystal lattice of another substance. The crystals are then separated from the saline liquor and decomposed for fresh water production.

Economic Considerations

The cost of producing fresh water from saline water is easily computed for each particular pilot project and for commercial enterprises. The costs initially were not being itemized in similar methods however, and it was difficult to compare costs. The Office of Saline Water in 1956 worked out a standard procedure (8) for estimating cost so there could be a base for comparing operating costs at the various plants. This method does not include distribution costs.

Aside from determining the actual dollar and cents cost of producing the water, however, is the problem of determining when, where, and whether desalinization is cheaper than importing acceptable water. Koenig (9) has reported on his studies in this area of "Economic Boundaries". The basic question in many communities, in their search for a water supply source, is, "is it cheaper to desalinize a local saline supply or to import a more conventionally acceptable water?" The elements of conventional water systems and costs that are influencedby saline water conversion are the intake, raw-water storage, transmission, and treatment. Koenig summarizes, "the sum of the costs of those components eliminated by saline water conversion, less those incurred by the saline water source, is the 'break even cost for conversion' or the highest cost that conversion can reach and still compete with conventional supples." He develops a "break even" curve for a given situation to show that for increasing increments in water demand, a town can economically transport water over longer distances. This line of reasoning leads to the conclusion that saline water conversion in a growing community is a self-annihilating operation, because as the water demand increases, the value is

eventually reached at which it is more economical to import fresh water than to convert an equal quantity of local saline water. Koenig believes that for saline water conversion to have a lasting impact on water supply problems, the cost-capacity curve will require a greater slope and thereby approach the slope of cost-capacity curves for conventional supply techniques. He leaves definite impression that for large quantities of water, it will be cheaper to import than to desalinize local supplies because of the rapid decrease in cost of transporting large water quantities.

As always, there are two schools of thought and Othmer (10) states that the billions of dollars that Californians are spending to transport water over 4,000-foot mountains and distance of 750 miles is a very expensive method and no other water system as expensive will ever again be undertaken to bring water from such a distance to the seacoast. Using Los Angeles as an example, he states that desalinization plants could be built much faster than the long aqueducts and that water could be supplied at 40-45¢/1,000 gallons. He says that transported water to Los Angeles now costs about 50¢/1,000 gallons.

A less encouraging picture of the future of saline water conversion is painted by Morris (11). He states that with the California multiple-purpose water program, the cost of water at the Delta is only $1.075/1,000 gallons. He believes that in San Joaquin Valley, fresh water from the sea would have to compete with this cost. This, of course, is not possible at present power costs.

Applications

Pilot Plants - (6) (12) (13) The 1961 amendment to the Saline Water Act of 1952 authorized $75,000,000 for research and development, but nothing for construction. It was a separate authorization, enacted in 1958 in the

form of a joint resolution that provided ten million dollars for the construction of five demonstration plants. Four of the demonstration plants authorized have been built and are in operation. These plants are briefly described below. The fifth plant was redesignated a pilot plant because of its experimental nature, and its construction is nearly complete at Wrightsville Beach, North Carolina. The pilot plant will utilize a freezing process although other processes may also be investigated. The four demonstration plants are as follows:

1. Freeport, Texas; a one mgd capacity, long tube vertical salt water plant. The brine effluent concentration increases about fourfold. Product water has less than 50 ppm TDS and at times less than 10 ppm. Scale control is the main problem.

2. San Diego, California plant; is a one mgd sea water plant. It was designed for one million gallons a day at 190°F, but operated at 400,000 gpd at 250°F. This plant is considered the most successful of the four plants, (this plant was moved to Guantanamo Naval Basin in Cuba in 1964).

3. Webster, South Dakota; a 250,000 gpd electrodialysis plant for brackish water (1,800 ppm TDS). Water pretreatment includes removal of iron and manganese, typical months's cost per thousand gallons are: electric power 4.9¢, chemical 7.2¢, membrane and other replacements 11.6¢, for a total of 23.7¢.

4. Roswell, New Mexico; a one mgd vapor compression plant for brackish water (15,860 ppm TDS).

Commercial Uses

Several other plants have been constructed as commercial enterprises in the United States. There are plants at Coalinga, California (14), Morro Bay Power Plant near Morro Rock in San Luis Obispo County, California (15), three plants in Florida (16) Gettysburg Air Force Base (17) Virgin Islands (18) and Buckeye, Arizona (19). These are only a few of the plants as there are more than 100 electrodialysis units installed around the world

TABLE I

SUMMARY OF OPERATING COSTS

	Florida								
	Morton County	Brevard County	Sarasota County	Gettysburg S. Dakota		Coalinga Calif.	Virgin Islands	Morro Bay Calif.	Buckeye Ariz.
Type	Electro-dialysis	Electro-dialysis	Electro-dialysis	Electro dialysis		Electro-dialysis	Flash Evapor.	Submerged tube Evapor.	Electro-dialysis
TDS Raw Water (ppm)	1225	2053	2169	1900	1900	2392	Sea Water	Sea Water	2140
TDS Finished Water (ppm)				500	920	402	5	50	484
Capacity (gpd)	2 mgd	2 mgd	2 mgd	40,000		28,000	275,000	144,000	650,000
Capitol Cost (thous. dollars)	$ 650	$ 1150	$ 1400	$ 69		$ 105			$ 305
Unit Cost									
Operating Cost									
Electricity	0.081	0.175	0.200	0.18	0.11	0.21	0.085[a]		0.129
Chemicals	0.04	0.036	0.046	0.09	0.09	0.06	0.12		0.06
Prefiltration	0.03	0.030	0.030						
Fuel							0.372[b]		
Maintenance									
Membranes	0.038	0.066	0.084	0.13	0.13	0.23			0.075
Labor	0.014	0.025	0.030	0.27	0.27	0.17	0.050		0.069
Other equipment	0.011	0.016	0.019	0.03	0.03	0.03	0.050		0.064
Filters						0.19			0.032
Amortization (5%/25 years only)	0.064	0.112	0.136	0.35	0.35	0.54	0.39		0.255
Total Cost/1000 gallons	0.278	0.460	0.545	1.05	0.98	1.43	1.067	1.20[c]	0.63

a 8 mills/kwhr
b based on 25¢/1,000,000 BTU
c @ 100% capacity & fuel cost 35¢/1,000,000 BTU

to produce fresh water from brackish water (1,000-5,000 ppm) (20). The costs of many of these plants are summarized in Table I.

A distillation plant in the Virgin Islands (18) was built to replace water supply that was costing about $5.00/1,000 gd. Anticipated cost was $1.75/1,000 gd. Based on the standards of OSW, the cost is $1.07/1,000 gd but the actual cost is about $2.17, the price charged to the customers.

The first land based water evaporation plant in the United States was constructed at Morro Bay in 1953. It was a submerged tube evaporator type. It operated usccessfully for the five years reported on with total cost of production of $2.50/1,000 gd (if operated at full capacity).

Bornhill (16) reports on three two-mgd electrodialysis units used to treat brackish waters in Florida (1,200-2,200 ppm TDS). He estimates, based on two-mgd capacity, that the cost varies from 27.8¢ to 54.5¢/1,000 gd. He states that the cost range will be reduced to 10-30¢ in the next three years.

Electrolytic demineralization of brackish water (2,100 ppm) at Gettysburg Air Force Station is reported by Pruel (17). It was placed in service in 1959, operates at a cost of 98¢/1,000 gd and the water is reduced to 920 ppm. He states this is half of the cost of the estimated product cost for a standard bed-type ion exchange plant. He believes that the water can actually be produced at less than 98¢/1,000 gd.

The cost of the electrodialysis plant at Buckeye, Arizona has recently been reviewed by Hanmer (19). The plant has a capacity of 650,000 gpd. The present cost is 63¢/1,000 gd, however, the plant operated much of the time below the rated capacity. The cost would be 32¢/1,000 gd if the plant could operate at full load.

A very large distillation plant is proposed in the Southwest Water Plan (21) as an alternative plan to provide 1.2 million acre-feet annually for the projected municipal and industrial water use in Central Arizona. The desalting plant would be located in Yuma and would cost about $900,000,000 for desalting plants, intakes, and return channels, but exclusive of associated thermoelectric generating plants. It would consist of several (nine) 150 mgd plants, each combined with a thermoelectric power plant (417 MWHR generator stations, net for sale). The investment cost would be $86,000,000 for the water plant and water cost would be 28¢/1,000 gallons. Of this, 10¢ is capital cost and 13¢ is energy cost. These costs are for a coal-fired electric power plant. Gas-fired plant would result in unit cost of 32¢/1,000 gallons. The conversion plant in both cases would be a multistage flash evaporization process. It was proposed that a smaller prototype of 50 mgd would be constructed prior to constructing the larger plants.

Summary

In summary, the future of saline water conversion in providing high quality water will be limited to the area of "water treatment", and is not likely to be used as a salinity control procedure for maintaining "instream" water quality. It will be used to provide water that is sold directly to users that can afford high cost water. To date, the electrodialysis process has been profitably used in areas where relatively small volumes of brackish water require treatment, (2 mgd, 4,000 ppm TDS). Costs range from 50¢ to $1.50/1,000 gallons. In many instances, consumers had been paying more than ten times this cost for potable water.

Desalinization of sea water is best accomplished by a distillation

process. The costs are in the same range as for the membrane process. Low rates of 30¢/1,000 gal. are anticipated for large plants. Large plants are generally restricted to coastal areas because there are large quantities of salt water available at low heads and the problem of brine disposal is small compared to inland plants.

Desalinization of local saline waters will be cheaper in some situations than importing potable water. Many projects are now in progress that will provide considerable data on operation and capital costs for operating smaller units.

Very large plants to be operated in conjunction with large thermal power plants, have been proposed in the Southwest Water Plan. A plant as large as 50 mgd has been proposed as a step to the ultimate construction of a 150,000,000 gallon plant, and then the construction of a 1.35 billion gpd complex of these plants. Water costs are expected to reach lows of 28¢-30¢ in this size range.

It is not anticipated that the cost of producing water by desalinization will ever be reduced to that required for irrigation use.

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